COWRIE SEAGEN-07-07

Measurement and assessment of background underwater noise and its comparison with noise from pin pile drilling operations during installation of the SeaGen tidal turbine device, Strangford lough

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04 September 2008

This report has been commissioned by COWRIE Ltd

Published by COWRIE Ltd.

ISBN: 978-0-9557501-9-9

Preferred way to cite this report:
Nedwell J R and Brooker A G *Measurement and assessment of background underwater noise and its comparison with noise from pin pile drilling operations during installation of the SeaGen tidal turbine device, Strangford Lough.* Subacoustech Report No. 724R0120 to COWRIE Ltd. ISBN: 978-0-9557501-9-9.

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Executive Summary

This report has been prepared by Subacoustech Ltd for Collaborative Offshore Wind Research Into the Environment (COWRIE).

A series of measurements were made of the underwater noise during underwater pin pile drilling operations as part of the installation of the SeaGen tidal turbine device in Strangford Lough, Northern Ireland. The data are presented in unweighted noise metrics such as RMS, Sound Pressure Level and Sound Exposure Level. The data are also presented as weighted levels above hearing threshold (dB_{ht}) for specific fish and marine mammal species.

Measurements of background underwater noise during periods when no drilling was being carried out have indicated high levels of high frequency background noise are present in the Strangford Narrows region of Strangford Lough. It is thought that this is due to the high speed of tidal flow in the region generating noise by interaction of turbulent water with the sea bed and at the water surface.

Measurements at ranges of 28 m to 2130 m from the drilling operation indicated that the unweighted, one second RMS Sound Pressure Levels varied from 105 to 139 dB re. 1 µPa. A fit to the measured data has indicated a Source Level for the drilling noise of 162 dB re. 1 µPa @ 1 m. The levels of underwater noise from the drilling operation are comparable with small vessel noise, and considerably lower than the levels of noise generated by other piling techniques such as impact piling or vibro-piling.

High levels of underwater noise can have an effect on underwater species, in that they are known to cause a behavioural avoidance response in fish and other marine animals, and in some cases where the level is very high can cause physical injury. The measured levels of underwater noise from the pin pile drilling indicate that the noise levels are very much lower than those that may cause fatality, physical injury or audiological injury to the species of fish and marine mammal considered.

Comparison of the measured background noise data with the hearing sensitivity of the harbour porpoise has indicated that this region is a noisy environment for marine animals that are sensitive to high frequency noise. The data for the drilling noise indicates that these species are unlikely to be able to hear noise from the drilling operation over the high levels of perceived background noise. This conclusion highlights the importance of considering the spectral perception of underwater noise by marine animals when estimating its impact.

The likelihood of avoidance of the drilling noise by species of fish and marine mammal has been assessed by using the dB_{ht} approach (Nedwell et al, 2007b) which estimates the perception or "loudness" of noise by weighting the measured noise levels by the published hearing threshold data for the species considered. The data indicates that the noise does not exceed the 90 dB_{ht} level, at which strong and sustained avoidance is expected, at any measured range. The 50 dB_{ht} level, at which a mild and brief reaction is expected in a minority of individuals, extends to a maximum range of 115 m.

The data therefore indicates that the species of fish and marine mammals considered are unlikely to be disturbed by the drilling noise unless they are in the close vicinity of the drilling operation.

1 Introduction

This report has been prepared by Subacoustech Ltd for COWRIE. It describes a series of underwater noise measurements undertaken during drilling operations for the pin piles used to secure the quadropod base of the SeaGen tidal turbine device in Strangford Lough, Northern Ireland. The results have been interpreted in terms of the potential impact this noise may have on marine species. Background noise measurements were also undertaken during periods when the drilling was not being carried out to determine pre-existing ambient underwater noise levels in the region.

It had been intended to include measurements of underwater noise generated by high pressure water jet cutting at the Strangford Lough site. The installation procedure for the construction project however, was changed and this technique was not required.

High levels of underwater noise and vibration are known to cause a behavioural avoidance response in fish and other marine animals, and in some cases can cause physical injury and fatality. The data are presented in appropriate unweighted noise metrics such as RMS, Sound Pressure Level and Sound Exposure Level. The data is also presented as weighted levels above hearing threshold (dBht) for specific fish and marine mammal species. An explanation of these measurement parameters is provided in Appendix A of this report.

The assessment has been prepared with regard to the hearing sensitivity of species of fish and marine life common to the area. To assess the likely behavioural response of a species of marine animal to underwater noise and vibration, a measure of its hearing sensitivity in the form of an audiogram is required. This report presents some of the more reliable data on hearing sensitivities of fish and marine mammals. For many species, however, there is either no sensitivity data available, or the data that is available is of poor quality. The approach that has been undertaken in this study is to base the assessment of underwater noise on the perceived level of sound for a number of species of fish and marine mammal that are present in the region, and other UK waters, and for which a good quality audiogram is available.

2 Assessment of underwater noise

2.1 Introduction

Sound travels much faster in water (approximately 1500 m.s-1) than in air (340 m.s-1). Since water is a relatively incompressible, dense medium the pressures associated with underwater sound tend to be much higher than in air. Background levels of about 130 dB re. 1 μPa for coastal waters (Nedwell et al., (2003 and 2007a)) and rivers are not uncommon. This level equates to about 100 dB re. 20 μPa in the units that would be used in air. Such levels in air would be considered to be hazardous, however, marine animals have evolved to live in this environment and are thus relatively insensitive to sound pressure when compared with terrestrial mammals.

2.2 Impact of underwater noise on fish and marine mammals

Over the past 20 years it has become increasingly evident that noise from human activities in and around underwater environments may have an impact on marine species. As a result, interest in the hearing of these species has increased, although to date, relatively few studies have tackled the issue of how the level of sound corresponds to its impact on fish and marine mammals.

2.2.1 Lethality and physical injury

There have been a number of reviews of the impact of high level underwater sound causing fatality and injury in human divers, marine mammals and fish (see for example Rawlins (1974), Hill (1978), Goertner (1982), Richardson *et al.,* (1995), Cudahy and Parvin (2001), Hastings and Popper (2005)). These reviews indicate that at very high exposure levels, such as those typical close to underwater explosive operations or offshore impact piling (pile driving) operations, fatality may occur in species of fish and marine mammal where the incident peak to peak sound level exceeds 240 dB re. 1 μPa. The likelihood of fatality increases with level above 240 dB re. 1 μPa. As the time period of the exposure increases, (represented by the impulse) there is also an increase in likelihood.

For smaller fish sizes of mass 0.01 g, Hastings and Popper (2005), and Popper *et al.,* (2006) recommend an interim no injury criteria for fish exposed to impact piling noise of 208 dB re. 1 μPa peak level (equivalent to 214 dB re. 1 μPa peak to peak level) or a Sound Exposure Level of 187 dB re. 1 μPa^2-s.

2.2.2 Auditory injury

At high enough sound levels, (generally taken to be in excess of 180 dB re. 1μPa) and particularly where there are repeated high level exposures from activities such as impact pile driving, seismic operations, or for continuous wave sound such as sonar, underwater sound has the potential to cause hearing impairment in marine species. This can take the form of a temporary loss in hearing sensitivity, known as a Temporary Threshold Shift (TTS), or a permanent loss of hearing sensitivity, known as a Permanent Threshold Shift (PTS).

There is data concerning incipient hearing damage in fish, including TTS measurements on goldfish (Cox et al. 1986, 1987), cod (Enger 1981), and Oscar fish (Hastings et al. 1986), and hearing damage in marine mammals from Schlundt et al. (2000) and Nachtigall et al. (2004) that indicate auditory damage in marine species may occur following exposure to high level underwater noise. The conservative limit proposed by the US National Marine Fisheries Service (NMFS) of 180 dB re. 1 μPa Sound Pressure Level limit has been considered in this respect. However, it should be noted that some authors have highlighted that this limit is not based on any firm scientific basis (Popper et al., 2006), and that the limit has no frequency dependence (Madsen et al., 2006).

2.2.3 Behavioural response

At lower Sound Pressure Levels it has been observed that a behavioural response in fish and marine mammals may occur. These reactions may include the animals leaving the area for a period of time, or a startle reaction may be observed.

Maes *et al.* (2004) studied the effects of fish avoidance in relation to fish deflection systems, installed to prevent fish from entering power station water inlets. For fish species that are comparatively sensitive to underwater sound such as the herring (*Clupea harengus)* and the sprat (*Sprattus sprattus)* average intake rates decreased by 94.7% and 87.9% respectively, indicating that fish were avoiding the high sound field surrounding the power station water inlet. The data indicated that for the fish species that were considered less sensitive to underwater sound only a moderate response to the sound was demonstrated. The efficiency for the flatfish species, the flounder (*Platichthys flesus)* was at 37%, and for the sole (*Solea solea)* was at 47%. Analysis of the results by Nedwell *et al.* (2007b) indicated that at levels of 90 dB above fish hearing threshold (dB_{ht}, see Appendix A) sound is of sufficient loudness to cause an avoidance response in 95% of individuals.

Currently, on the basis of the analysis of Maes' results, laboratory validation and re-analysis of marine mammal behavioural response to underwater sound in Nedwell *et al.* (2007b), the following assessment criteria have been proposed to assess the potential impact of the underwater noise on marine species;

- 90 dB_{ht} (*species*) – Strong avoidance reaction by most individuals.
- 75 dB_{ht} (*species*) - Significant avoidance reaction occurs in a majority of individuals.
- 0 – 50 dB_{ht} (*species*) – Low likelihood of disturbance

The authors have considered other metrics. Recently, Southall (2007) has suggested that audiogram-based metrics such as the dB_{ht} (*species*) may be inadequate to characterise the compression of the dynamic range and flattening of the hearing response that may occur in marine animals, although this has not yet been observed. The suggestion is based on the compression indicated in the human equal loudness contours of Fletcher and Munsen (1933), although more recent information such as the equal-loudness contours of ISO 226 :200 of 2003 indicate contours having a more limited degree of range compression, generally occurring at the lowest frequencies of human hearing, and which do not flatten out even at the highest sound levels measured. The dB(A), used for estimating human behavioural effects, and which is an audiogram-based metric, is actually based on such equal-loudness contours.

The authors propose a generic M-weighting for application to groups of marine mammals. While there is currently no experimental evidence to support the use of this metric it offers an interesting alternative to audiogram based methods and one which, in view of the limited frequency range, is easier to implement than audiogram-based metrics, which require recordings having an extended frequency range and dynamic range. This metric has not been used in this report since there is currently no criterion by which levels can be related to effect.

2.3 Underwater hearing threshold data

Figures 2-1, 2-2 and 2-3, present the cited audiogram data for species of fish and marine mammal. These data have been used to develop the Finite Impulse Response (FIR) filters that are used to process measurements in order to assess the perceived level of underwater sound by marine species.

2.3.1 Fish hearing

The audiograms highlight that typically fish hear at very low frequency (typically 10 Hz to 1000 Hz). Of the fish audiograms shown in Figure 2-1, the most sensitive to underwater sound is the herring (*Clupea harengus*) which is a hearing specialist, that is, it has a low hearing threshold (is relatively sensitive) to sound. Audiogram data from Enger (1967) for the herring indicates that compared to most fish species it has a fairly broad response to the low frequency components of underwater sound, with hearing threshold at levels below 80 dB re 1 µPa, over the frequency range from 32 Hz to 1000 Hz. The data suggest that the cod is also sensitive to underwater sound, but over a narrower, low frequency range. According to Chapman and Hawkins (1973) the peak hearing sensitivity for the cod is at a frequency of 160 Hz, where the hearing threshold is at a level of 75 dB re 1 µPa. At this frequency, the data suggest that cod hearing sensitivity is comparable with the herring.

Data for the dab (Chapman and Sand, 1974) indicate that this species is less sensitive to underwater sound. They are therefore likely to perceive a given underwater sound at a lower loudness level.

It is possible that some fish are sensitive to particle velocity rather than pressure over part or all of their hearing range (Popper et al. 2003).

2.3.2 Marine mammal hearing

In comparison to fish, marine mammal species such as the bottlenose dolphin (*Tursiops truncates*), harbour porpoise (*Phocoena phocoena*) and the killer whale (*Orcinus orca)* are sensitive to a very broad bandwidth of sound. The audiograms presented in Figure 2-2 indicate that they are responsive at frequencies from 100 Hz to 170 kHz. They possess sensitive hearing over the frequency range from 20 kHz to 150 kHz, where for example, the audiogram for the harbour porpoise (Kastelein, 2002) indicates that it is able to hear sounds below 40 dB re 1 Pa. This typically corresponds to the typical background noise level at these frequencies. The audiogram from Johnson (1967) indicates that the bottlenose dolphin also hears over the same broad frequency band, but that peak sensitivity is of the order of 10 dB less sensitive.

Figure 2-3 presents the underwater audiogram for several species of seal. The data for the common (harbour) seal (*Phoca vitulina*) from Kastak and Schusterman (1998) indicates that this species has better low and mid-frequency hearing than the harbour porpoise and bottlenose dolphin, with a frequency range from 100 Hz to approximately 5 kHz. Their hearing is not as sensitive at very high frequency as that of the dolphin and porpoise.

As there is no single published dataset for seal species that covers the full audiometric range, the FIR filter used for analysis of the data for the common seal uses the data of Kastak and Schusterman (1998) for the frequency range from 100 Hz to 6.4 kHz, and the data from Mohl (1968) over the higher frequency range from 8 to 128 kHz. As the data in Figure 2-3 suggests that the hearing of the grey seal (*Halichoerus grypus)* and harp seal (*Pagophilus groenlandicus)* are marginally less sensitive than that for the harbour (common) seal, the data for the harbour seal presented in this report represents a small overestimate of the perceived sound levels for these other seal species. The impact ranges predicted for the common seal would therefore be considered as conservative for these other seal species.

In some cases more than one audiogram is available for a given species, and they rarely agree. In general, the lowest level of threshold has been preferred, both on the basis of it offering a precautionary level, and because the results are the least likely to have been masked by noise.

2.4 Selection of species

The species upon which the dB_{ht} analysis has been conducted in this study have been selected based upon their regional significance and the availability of a good quality audiogram.

The fish and marine mammal species that have been selected for this study, and their classification in terms of their sensitivity to sound based on currently available audiograms are;

the herring (*Clupea harengus)*, a fish hearing specialist that is the most sensitive marine fish to underwater sound.

the cod (*Gadus morhua*), a fish hearing generalist that is reasonably sensitive to underwater sound.

the dab (*Limanda limanda)*, a flatfish species with generalist hearing capability, but is the most sensitive flatfish to underwater sound.

The marine mammal species considered in this study are;

the harbour porpoise (*Phocoena phocoena)*, a marine mammal (toothed whale) that is the most sensitive marine mammal to high frequency underwater sound.

the harbour (common) seal (*Phoca vitulina)*, a pinniped that is the most sensitive of the seal species, or other marine mammals to mid-frequency underwater sound.

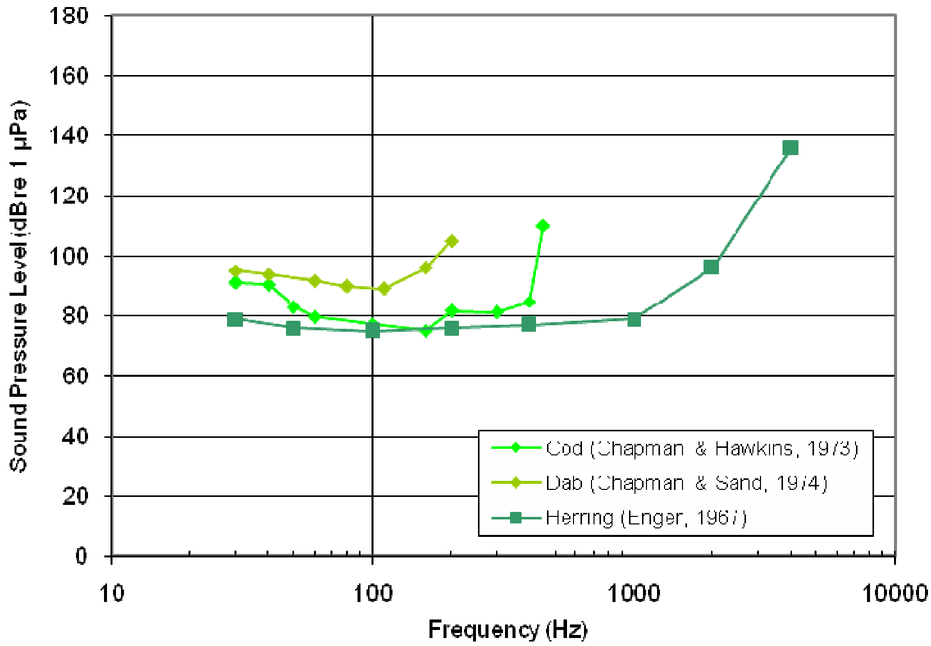

Figure 2-1. Hearing threshold levels for various species of fish

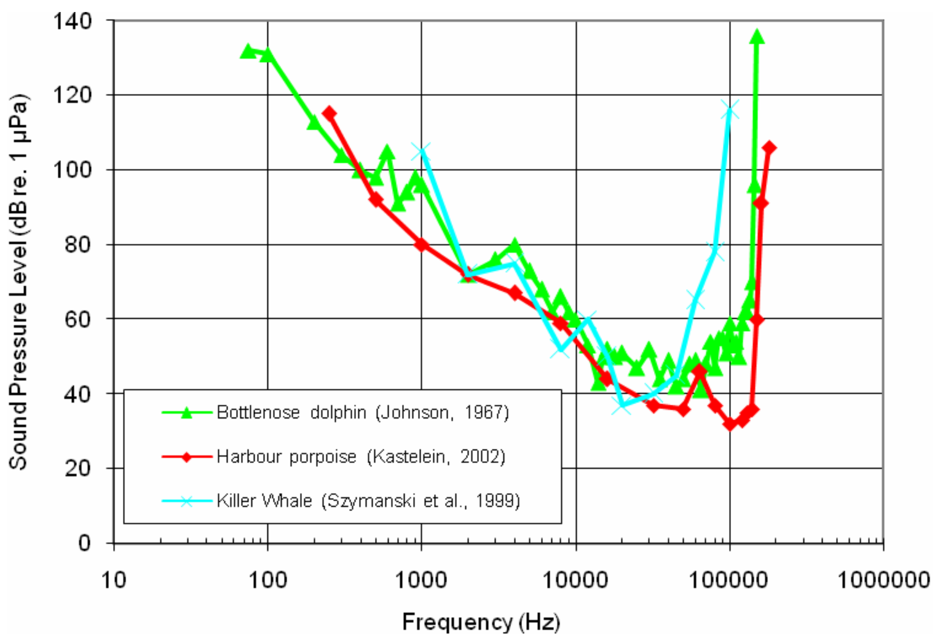

Figure 2-2 Hearing threshold levels for various species of marine mammals

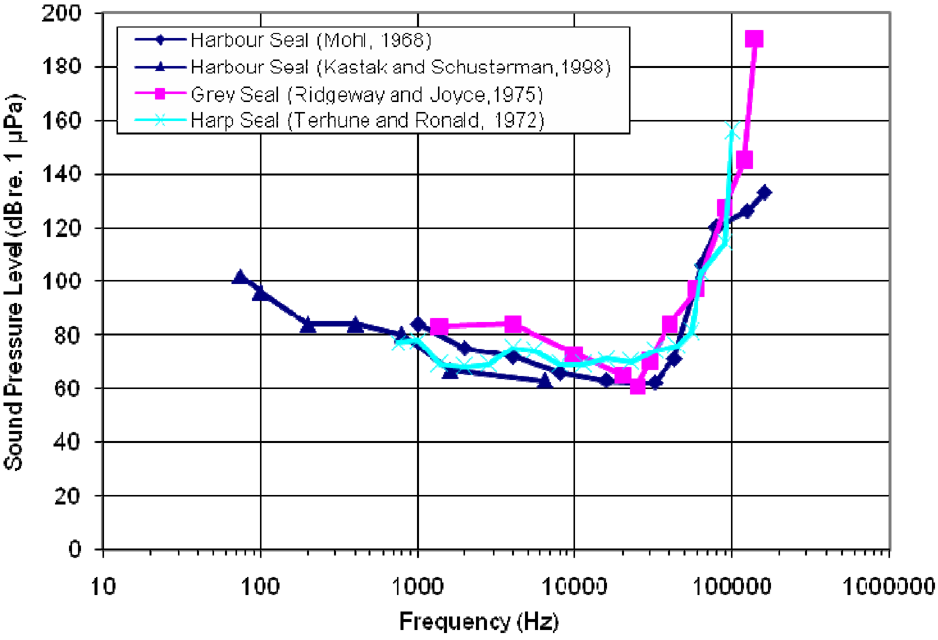

Figure 2-3 Hearing threshold levels for various species of seal

3 Underwater sound measurements

3.1 Introduction

The SeaGen device is situated approximately 1 km south of the ferry crossing route between Strangford and Portaferry, and approximately 400 m from the shore. Underwater noise measurements were undertaken in Strangford Lough on 23rd April 2008 between 09:00 and 21:00 during drilling operations on the North-West foot of the SeaGen base.

The drilling operation to secure the pin piles used a Seacore / Wirth B5 pile top drill with a drill bit size of 1150 mm. This method involves reverse circulation drilling, where high pressure air is piped down through the drill pipe and injected just behind the drill bit. This causes sea water and any cuttings from the drill bit to rise to be removed. A specification of the drill is provided below.

Seacore / Wirth B5 pile top drill specifications	
Weight	**15 tonnes**
Input Power	**80 kW**
Hydraulic input	**240 lpm @ 175 bar continuous**
Maximum torque	**54 kNm @ 200 bar**
Maximum Speed	**37 rpm**
Diameter through power swivel	**150 mm**
Maximum diameter	**1300 mm**

Each socket was drilled to a depth of 7.4 m below the seabed. Drilling was predominantly through bedrock material except for a small amount of overlying loose rocky material over some of the sockets. A picture of the drilling device is shown in Figure 3-1. The drilling rig can be seen as the yellow device sitting on top of the pile with the seawater being ejected to the side of the platform.

Figure 3-1 Photograph of pin pile drilling operations during the installation of the SeaGen tidal turbine device, Strangford Lough, Northern Ireland.

The measuring equipment was deployed from the survey vessel Cuanshore. During measurements of the drilling operations the vessel was moved as close to the drilling rig as possible. The ships engines and all electrical equipment on board were turned off and the vessel was then allowed to drift away from the noise source. This method allowed measurements to be taken at ranges between 23 m and 2130 m from the drilling operation. The hydrophone was at a depth of 10 m below the water surface for most of the measurements. During a short period of measurements in an area of shallower water the hydrophone was raised to 3 m below the water surface.

Background underwater noise measurements were also carried out during periods when no drilling was taking place in order to determine the pre-existing noise levels in the Strangford Lough region.

3.2 Measurement equipment.

All underwater sound measurements undertaken as part of this study where undertaken using a Bruel and Kjaer 8106 low noise hydrophone. This hydrophone is able to measure underwater sound to levels well below sea state zero noise. This is important if the recordings are to be compared with the hearing response of species of marine mammal, many of which are able to perceive noise at low levels.

The Bruel and Kjaer 8106 hydrophone has a linear sensitivity to underwater sound over the frequency range from 7 Hz to 80 kHz. The calibration chart for the sensor, traceable to international standards, is provided at Appendix B. However, Bruel and Kjaer also provide sensitivity data outside of the linear range, from 0.25 Hz to 150 kHz, so that the acoustic data can be extended well beyond the linear frequency range specified above. This broad, well specified frequency calibration allowed an inverse filter to be applied to flatten the response of the hydrophone. While other hydrophones are available with a wider frequency range of constant sensitivity, they are typically less sensitive and not able to record noise at the low levels marine mammals can hear.

All underwater sound recordings undertaken in the course of this study were digitised and stored on a portable laptop computer system at a sample rate of 350, 000 samples per second. By the Nyquist Criterion this provides acoustic data to a frequency of 175 kHz. Subsequent analysis of the acoustic data was however, conducted over the frequency range from 1 Hz to 120 kHz. Spectral levels of noise in this report are presented over the frequency range from 1 Hz to 100 kHz.

3.3 Background underwater noise, Strangford Lough

A measure of the ambient noise environment is of critical importance in assessing the impact of noise from an activity. Sea noise levels, particularly in shallow inshore coastal regions can vary considerably. Developments related to oil and gas exploration, long range shipping, etc., can cause a consistent increase in the ambient noise, particularly at low frequencies between approximately 10 Hz to a few hundred Hz, but there are also many time varying factors related to the weather, sea state, tide and local vessel traffic that can increase the underwater noise in a region.

All of the measurements were taken on 23rd April 2008. The sea was calm, and the day started out sunny but became more overcast. Winds were light, up to Force 3 (maximum of 12 mph).

Strangford Lough is an unusual environment from the point of view of underwater noise. Figure 3-2 presents a comparison of typical spectral levels of background underwater noise measured at two positions near Strangford Lough drilling site in comparison with spectral levels of background underwater noise measured in a typical shallow coastal water site in the Thames Estuary obtained during underwater noise measurements at the

Kentish Flats Offshore Wind Farm (Nedwell *et al.* 2007a). In the low frequency band between 1 Hz to 20 Hz the underwater noise is dominated by noise from wave motion. The data indicates that noise levels in this frequency band are slightly higher at the Thames Estuary site, most likely due to the Strangford Lough site being more sheltered. The middle frequency band between 20 Hz to approximately 200 Hz indicates significant tonal components at the Strangford Lough site that are not evident in the Thames Estuary data. These tonal components are most likely engine or propeller noise from small vessels operating in the Strangford Lough region. In general, the broadband high frequency range from 200 Hz up to the highest frequencies measured shows an apparent increase in noise levels at the Strangford Lough site over those measured in the Thames Estuary, although there is a slight variation over the frequencies at which the increase is present at the two Strangford Lough positions. Unusually, it is thought that high tidal flow states create high levels of underwater noise due to the interaction of the turbulent water with the seabed and waves at the water surface. The effect of the flow is to increase ambient underwater noise levels over the frequency range between approximately 200 Hz to 100 kHz.

The data measured in the Strangford Narrows region indicates that broadband one second Sound Pressure Levels of background underwater noise vary from 115 to 125 dB re. 1 μPa, with mean levels at 120 dB re. 1 μPa. These levels are typical for shallow coastal water regions, in which noise levels can vary from between 90 to 155 dB re. 1 μPa. (Nedwell *et al*., 2003). As explained above, the levels of high frequency noise in the Strangford Narrows region are higher than those at other coastal regions. The overall broadband levels of underwater noise however, are dominated by low frequency shipping noise so the broadband Sound Pressure Levels are not heavily influenced by the high frequency components.

Figure 3-3 presents the range of perceived levels of background underwater noise for each of the species considered measured during periods when no drilling was taking place. The data is presented as a percentage of occurrences per 4 dB bin. The perceived levels of background noise for the species of fish and marine mammals vary from 0 dB_{ht} for the trout to over 80 dB_{ht} for the porpoise.

The range of dB_{ht} levels for the species considered in this study and the mean perceived levels are presented in Table 3-1 below. Nedwell *et al*, (2003) presents both broadband unweighted Sound Pressure Levels and data in the dB_{ht} metric for ambient noise in shallow coastal waters. The data, from baseline noise studies prior to the offshore wind farm developments at the North Hoyle and Scroby Sands sites are presented in Table 3-2. The data indicates that perceived levels of noise for species of fish that are sensitive to relatively low frequency noise are similar for both the coastal water sites discussed in Nedwell *et al*. (2003) and the Strangford Lough region. The data for perceived levels of noise at coastal water sites for marine mammals, in comparison with background noise measured in the Strangford Narrows region indicates that species of marine animal with sensitive hearing at high frequencies such as the harbour porpoise are likely to perceive high levels of background noise in regions of high tidal flow. This highlights the importance of ‘spectral’ comparison of background underwater noise when discussing the behavioural impact of noise on species of fish and marine mammal.

Species	Range of Measured Levels (dB_{ht})	Mean Level (dB_{ht})
Dab	5 - 31	17
Cod	22 - 43	33
Herring	30 - 47	39
Trout	0-6	0
Common Seal	42 - 54	49
Harbour porpoise	60 - 81	73

Table 3-1 Summary of dB_{ht} levels of measured ambient underwater noise in the Strangford narrow region of Strangford Lough (April 23rd, 2008)

Species	**Range of measured levels (dB_{ht})**	Mean Level (dB_{ht})
Dab	**15 - 60**	**35**
Cod	**15 - 65**	**35**
Herring (Estimated)	**20 - 70**	**40**
Common Seal	**25 - 65**	**35**
Harbour Porpoise	**40 -75**	**55**

Table 3-2. Summary of dB_{ht} levels from measured ambient sea noise at the North Hoyle and Scroby Sands Offshore Wind Farm sites (Nedwell et al, 2003)

Summary

1. **Background underwater noise measurements were undertaken in the vicinity of the SeaGen tidal turbine drilling site in Strangford Lough. These data have been compared to the published hearing threshold data for species of fish and marine mammal to obtain perceived levels above hearing threshold (dB_{ht}) of background noise.**
2. **Spectral analysis of the background noise data indicates that there are high levels of noise in the upper frequency band between approximately 200 Hz and 70 kHz when compared with spectral levels of background noise at other coastal water sites. It is thought that this increase in noise is due to the high tidal flow rates through the Strangford Narrows region.**
3. **The data indicates that unweighted, broadband levels of background noise, and perceived levels of background noise in the Strangford Narrows region for species of fish are typical for shallow coastal water sites.**
4. **Analysis of the data to obtain perceived levels of noise for species of marine mammal that are sensitive to relatively high frequency sound indicates that these species hear high levels of background noise in the Strangford Narrows region.**

3.4 Underwater noise from the SeaGen pin pile drilling operation, Strangford Lough

3.4.1 Introduction

Underwater noise measurements during pin pile drilling operations to secure the quadropod base of the SeaGen tidal turbine device to the seabed were undertaken on the 23rd April 2008 between the times of 09:00 and 17:30. The drilling logs provided by Seacore indicate that the drill bit was at a depth of 2.67 m at the start of the measurement period and had reached a depth of 6.27 m by the end.

3.4.2 Unweighted data

Figure 3-4 presents a typical time history of underwater noise at a range of 54 m from drilling operations in Strangford Lough. The underwater noise is characterised by regular peaks in the noise levels above that of the drill alone, and of the background underwater noise. These peaks may correspond to the drill head periodically grating against harder substrate material. At this range from the drilling operation the one second RMS sound pressure varied from 2.3 to 4.2 Pa (127 to 133 dB re. 1 μPa RMS). The analysis of the data file indicated that the mean RMS level of the sound during this period was at a level of 3 Pa, or a Sound Pressure Level of 130 dB re. 1 μPa. This is equivalent to a one second Sound Exposure Level of 130 dB re. 1 μPa^2-s.

Figure 3-5 presents a corresponding underwater noise time history measured at a distance of 830 m from the drilling operation. Slight peaks in underwater noise pressure levels can be seen in the time history and the drilling is still audible, however the noise from the drilling operation is predominantly masked by background noise at this range. The one second RMS pressure levels during this period varied from 0.55 to 0.65 Pa (115 to 116 dB re. 1 μPa).

Figure 3-6 presents an underwater noise time history during a period when no drilling was being carried out. One second RMS sound pressure varied from 0.58 to 0.71 Pa (115 to 117 dB re. 1 μPa). This suggests that at a range of approximately 800 m from the drilling operation the underwater noise is of the same level or below background noise levels in the Strangford Lough region.

Figure 3-7 presents the spectral levels of noise for the two underwater noise time history files discussed above, in comparison with several files taken at various ranges from the drilling operation and the spectral levels of background underwater noise in the Strangford Lough region. Comparison of the data indicates a trend whereby the spectral levels of noise decrease with increasing range. This trend is more apparent for the low frequency components of the noise. The data indicates that the drilling operation produces underwater noise with frequency components from 20 Hz to 100 Hz. At higher frequencies the noise shows little variation indicating that these components of noise do not contribute very much to the overall noise levels. Figure 3-7 also indicates the influence of flow noise on the spectral levels of noise in the Strangford Narrows region. The period of down time for the drilling operation during which background noise levels were recorded was during a period of high tidal flow, whereas the other data presented in the figure were obtained close to slack water at high tide. There is a considerable increase in levels of underwater noise in the frequency range from 3 kHz to 100 kHz during the period of high tidal flow due to noise possibly created by interaction of turbulent water with the seabed and at the surface.

Figure 3-8 presents a comparison of spectral levels of noise during drilling operations at a period of high tidal flow in comparison with the spectral levels of background noise discussed above. The levels of noise in the high frequency band between 3 kHz and 100 kHz are considerably higher than those presented in Figure 3-7 probably indicating the increased tidal flow influences the noise levels in this frequency band. This increase is particularly apparent in the measurements taken between approximately 800 and 1000 m. These measurements were taken to the north of the drilling operation in a region between Portaferry and Strangford. The tidal flow in this region is particularly fast therefore creating high levels of underwater noise.

Figure 3-9 presents a summary of the one second Sound Pressure Levels of underwater noise measured at ranges from 28 to 2130 m from the drilling operation. The data indicates a gradual decrease in noise levels with range consistent with that from a noise source in the underwater environment. The fit to the data indicates a broadband Source Sound Pressure Level noise of 162 dB re. 1 μPa @ 1 m, with the underwater sound decaying at approximately 16 log r, where r is the range in metres. This level of noise is comparable with the noise generated by small vessels such as small tugs and crew boats (Richardson *et al.*,1995), and considerably lower than that measured during activities such as blasting and impact piling.

Table 3-3 presents a summary of maximum, minimum and mean Sound Pressure Levels of underwater noise at various ranges from the drilling operation. The measurements at a range of 28 m from the drilling operation indicate mean Sound Pressure Levels of 136 dB re. 1 μPa. The data indicate that the noise decreases with range from the drilling to mean Sound Pressure Levels of 110 dB re. 1 μPa. at a range of 2130 m. Table 3-3 also presents the maximum, minimum and mean sound pressure levels of background underwater noise recorded during periods when no drilling was occurring. The mean Sound Pressure Level during background measurements was 120 dB re 1μPa. Comparison of background levels with the mean level at 464 m indicates that at this range from the drilling operation the noise falls below background levels.

		SPL (dB re. 1 μPa) SEL (dB re. 1 μPa^2-s)		
Filename	**Condition**	**Max**	**Min**	**Mean**
15-05-47'	**Drilling operational, 28 m range**	**139**	**134**	**136**
15-06-10'	**Drilling operational, 54 m range**	**133**	**127**	**130**
15-07-01'	**Drilling operational, 112 m range**	**134**	**129**	**130**
15-08-25'	**Drilling operational, 222 m range**	**128**	**124**	**125**
15-11-24'	**Drilling operational, 464 m range**	**121**	**119**	**120**
15-16-59'	**Drilling operational, 830 m range**	**116**	**115**	**115**
15-28-20'	**Drilling operational, 1640 m range**	**113**	**110**	**111**
15-38-27'	**Drilling operational, 2130 m range**	**126**	**105**	**110**
-	**No Drilling. Background.**	**125**	**115**	**120**

Table 3-3 Summary of unweighted Sound Pressure Levels (equivalent to one second Sound Exposure Levels) of underwater noise during pin pile drilling operations as part of the installation of the SeaGen tidal turbine device, Strangford Lough (April 23th, 2008)

3.4.3 dB_{ht} (frequency weighted) data

Figure 3-10 presents a summary of the measured underwater noise data analysed in terms of the hearing sensitivity of the seal. The data indicates that at ranges between 28 m and 2130 m, the one second, RMS dB_{ht} levels for the seal vary from 59 to 30 dB_{ht}. At ranges of approximately 300 m from the drilling operation, the perceived level falls below the minimum background levels. At ranges greater than 300 m, therefore the overall perceived levels of noise are dominated by background noise. The higher levels of noise at ranges greater than 300 m shown in Figure 3-8 are therefore likely to be background noise. The fit to the dB_{ht} data for the seal indicates a perceived Source Level for this species of 77 dB_{ht}(*phoca vitulina*) @ 1 m, with the underwater sound decaying by approximately 14 log r, where r is the range in metres.

Figure 3-11 presents a summary of the measured data analysed to obtain one second RMS dB_{ht} levels for the herring. The data indicates that at ranges of 28 m to 2130 m this species will perceive the noise at levels from 62 to 25 dB_{ht}(*clupea harengus*). The fit to the dB_{ht} data indicates a perceived Source Level for the herring of 83 dB_{ht} @ 1 m, with the underwater sound decaying at approximately 16 log r.

Figure 3-12 presents data for perceived noise levels for the harbour porpoise at ranges of between 28 m and 200 m from the drilling operations in Strangford Lough, in comparison with perceived levels of background noise. The data is presented as a frequency of occurrences of perceived levels per 4 dB bin. The data indicates that perceived levels of background noise are generally higher than perceived levels of drilling noise, with drilling noise only occasionally increasing above minimum background noise levels. The most frequent level of perceived drilling noise was at 62 dB_{ht}(*phocoena phocoena*). Data for perceived levels of background noise indicate that there is a wider spread of perceived levels with the most frequent perceived level occurring at 76 dB_{ht}.

The data therefore indicates that porpoise are unlikely to be able to hear the drilling noise at ranges beyond a few metres above the high levels of background noise present in the Strangford Lough region. This species has therefore been left out of further analysis and is not included in the remainder of this report.

Figure 3-13 presents a summary of the fit to the measured data of drilling noise in Strangford Lough for each of the species considered The data indicates that the herring, cod and seal perceive the noise at the highest levels, with the dab and trout perceiving levels at considerably lower levels. As with human perception of sound, where the level is above 90 dB_{ht} (i.e. 90dB(A)), the sound is loud and likely to cause a strong avoidance response in individuals. For the species considered, the 90 dB_{ht} strong avoidance level is not exceeded at any range from the drilling operation.

Table 3-4 presents a summary of behavioural avoidance ranges from the drilling operation based on the 75 dB_{ht} perceived noise level, and the 50 dB_{ht} perceived noise level, and the range to perceived background noise levels. The data indicates that for the species considered a mild avoidance response in the majority of individuals may occur to a maximum range of 3 m from the drilling device. The 50 dB_{ht} behavioural avoidance range extends to a maximum of 115 m from the drilling operation for the herring, with all other species considered only perceiving this level of noise at closer ranges. The perceived noise levels fall below background noise levels only a few hundred metres from the drilling operation.

Species	75 dB_{ht} mild avoidance range	50 dB_{ht} low likelihood of disturbance range	Range to perceived background levels
Cod	2.5 m	75 m	750 m
Dab	1 m	16 m	600 m
Herring	3 m	115 m	550 m
Trout	<1 m	<1 m	-
Harbour seal	1.5 m	85 m	100 m

Table 3-4 Summary of behavioural avoidance ranges from the foundation drilling operation during installation of the SeaGen tidal turbine device, Strangford Lough.

Summary

1. Underwater noise measurements at ranges of 28 m to 2130 m from a pin pile drilling operation were undertaken in the Strangford Narrow region of Strangford Lough. The measured data has been compared with hearing threshold data for species of fish and marine mammal to obtain perceived levels of noise from the drilling.
2. The fit to the measured data indicates a Source Level of the drilling noise of 162 dB re. 1 μPa. These levels of noise are considerably lower than those that may cause fatality, physical injury or audiological injury to species of fish and marine mammal.
3. The data analysed to obtain dB_{ht} levels for the species considered has been used to predict behavioural avoidance ranges from the drilling noise. The data indicates that species of fish and marine mammal are unlikely to be disturbed unless they are in the close vicinity of the drilling operation.
4. dB_{ht} data for the harbour porpoise has indicated that this species is unlikely to be able to hear the drilling noise. It is thought that this is due to the increased levels of high frequency background noise in the Strangford Lough region masking the noise from the drilling operation.

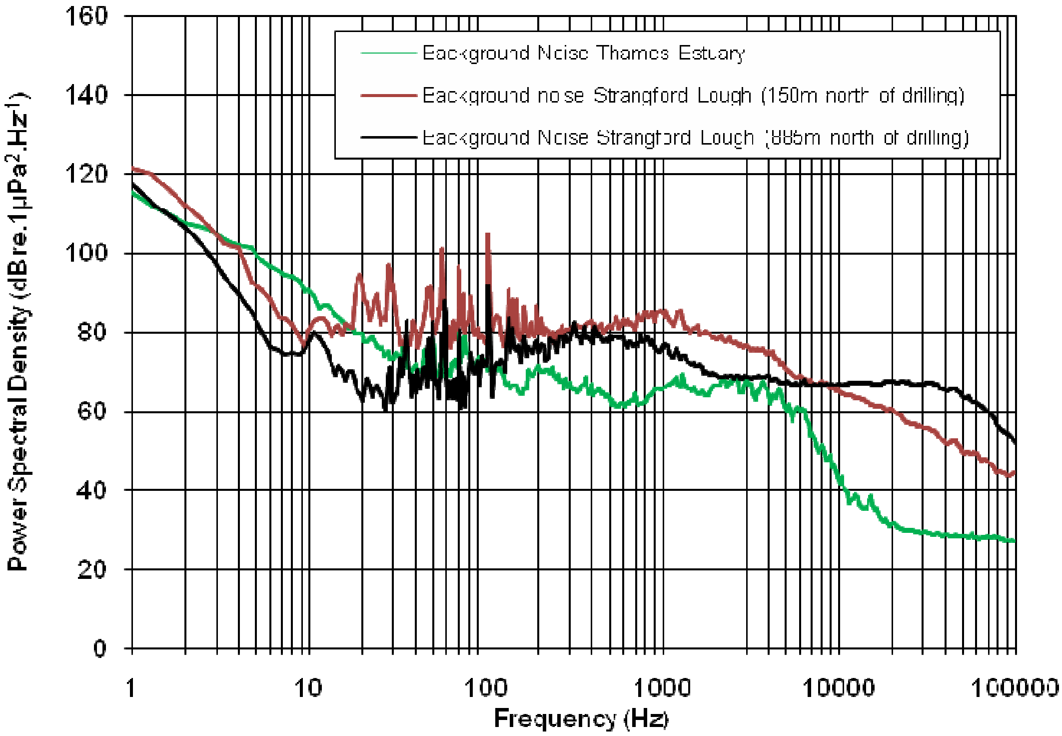

Figure 3-2 Comparison of spectral levels of background underwater noise at Strangford Lough with background underwater noise at a typical shallow coastal water region in UK waters

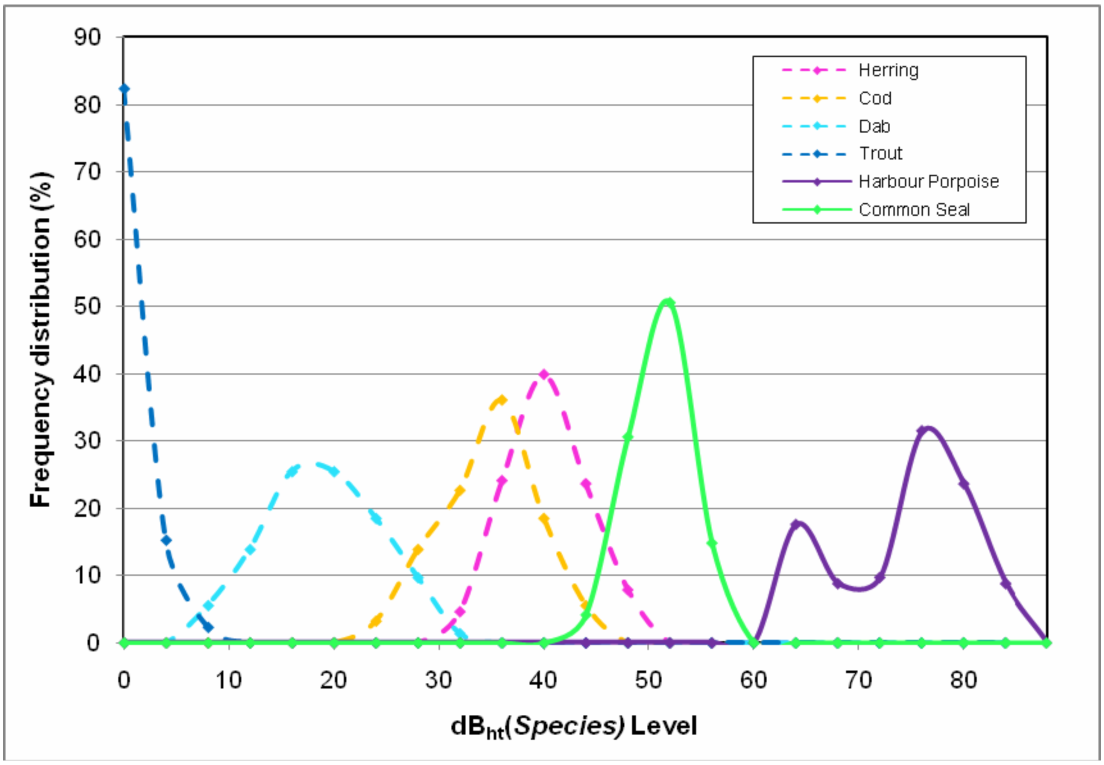

Figure 3-3 Summary of one second RMS dB$_{ht}$ levels of background underwater noise in Strangford Lough for various species of fish and marine mammal. Data is presented as a frequency distribution of perceived levels

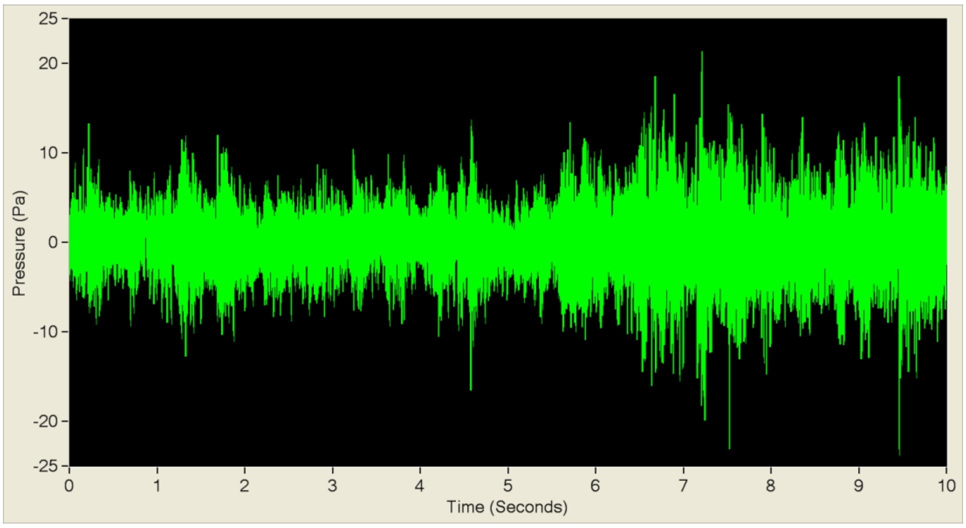

Figure 3-4. An underwater noise time history at a range of 54 m from the foundation drilling operations during installation of the SeaGen tidal turbine device, Strangford Lough. (April 23rd 2008, 15-06-10)

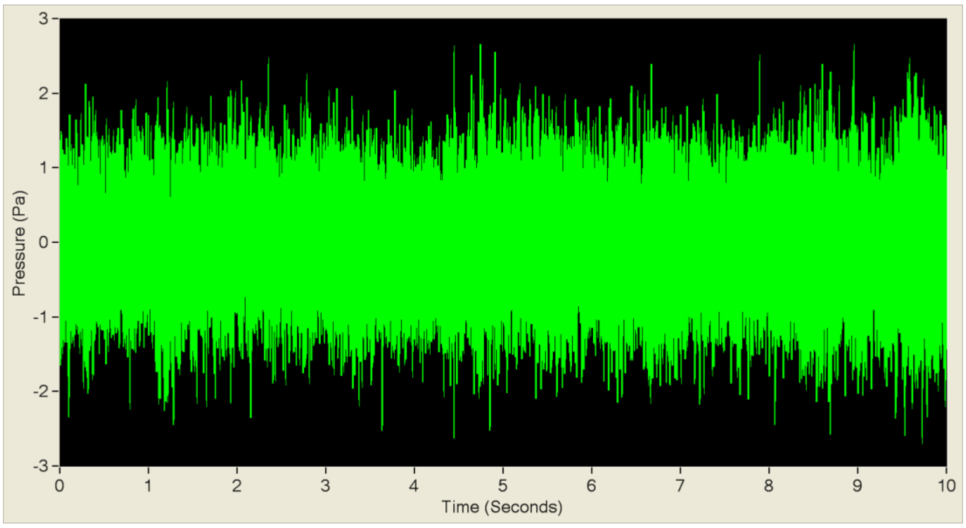

Figure 3-5. An underwater noise time history at a range of 830 m from the foundation drilling operations during installation of the SeaGen tidal turbine device, Strangford Lough. (April 23rd 2008, 15-16-59)

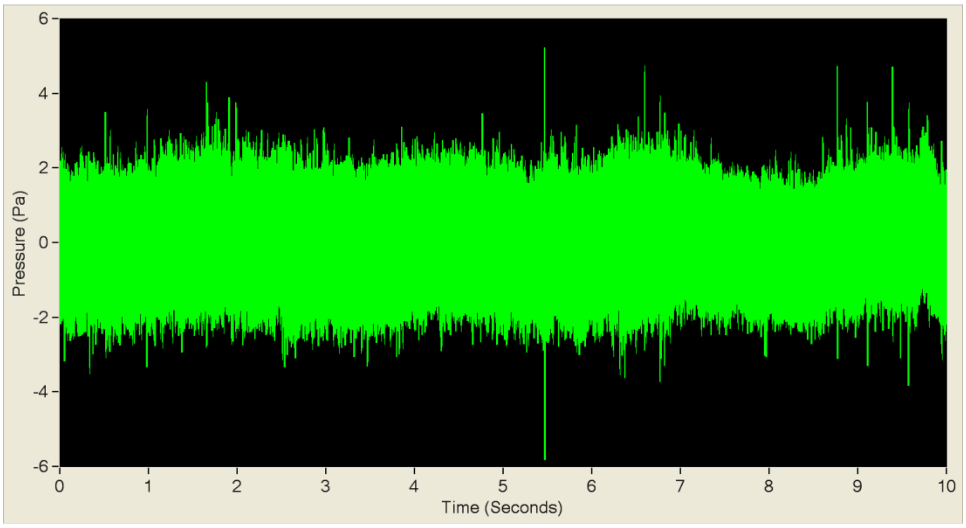

Figure 3-6. An underwater noise time history of background underwater noise, Strangford Lough. (April 23th 2008, 20-00-18)

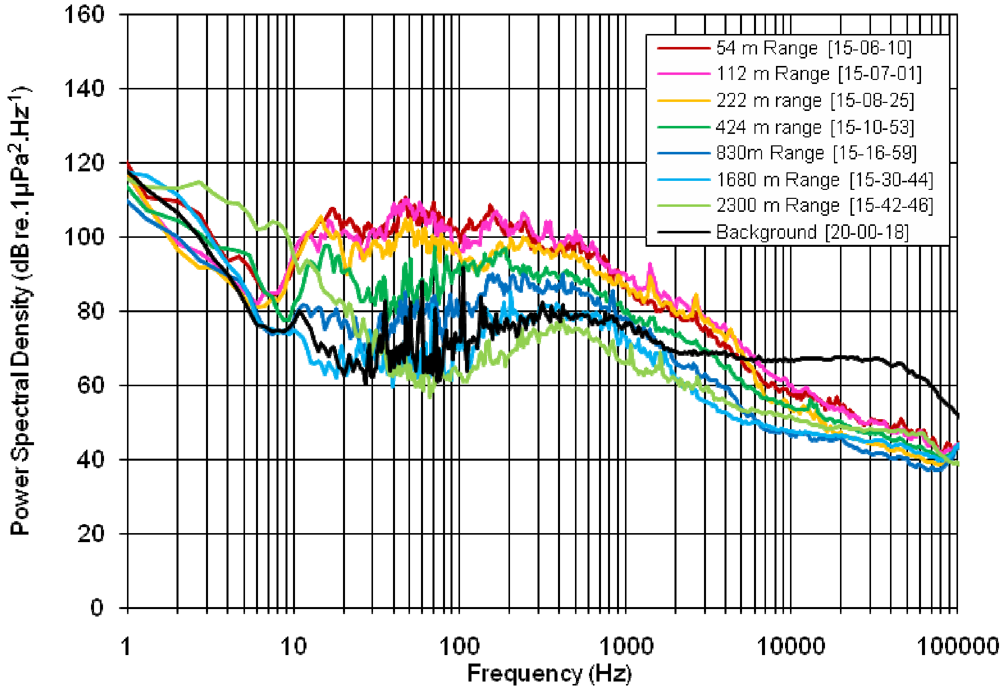

Figure 3-7 Comparison of the spectral levels of underwater noise at increasing range from foundation drilling operation during installation of the SeaGen tidal turbine device, Strangford Lough. [Drift 6]

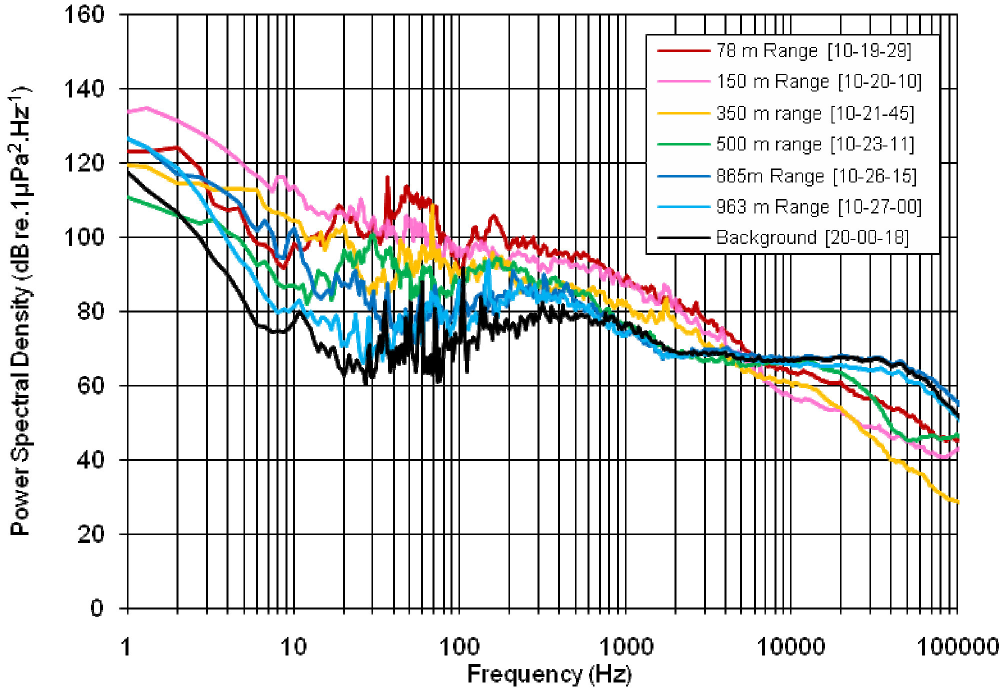

Figure 3-8. Comparison of the spectral levels of underwater noise at increasing range from foundation drilling operation during installation of the SeaGen tidal turbine device, Strangford Lough. [Drift 1]

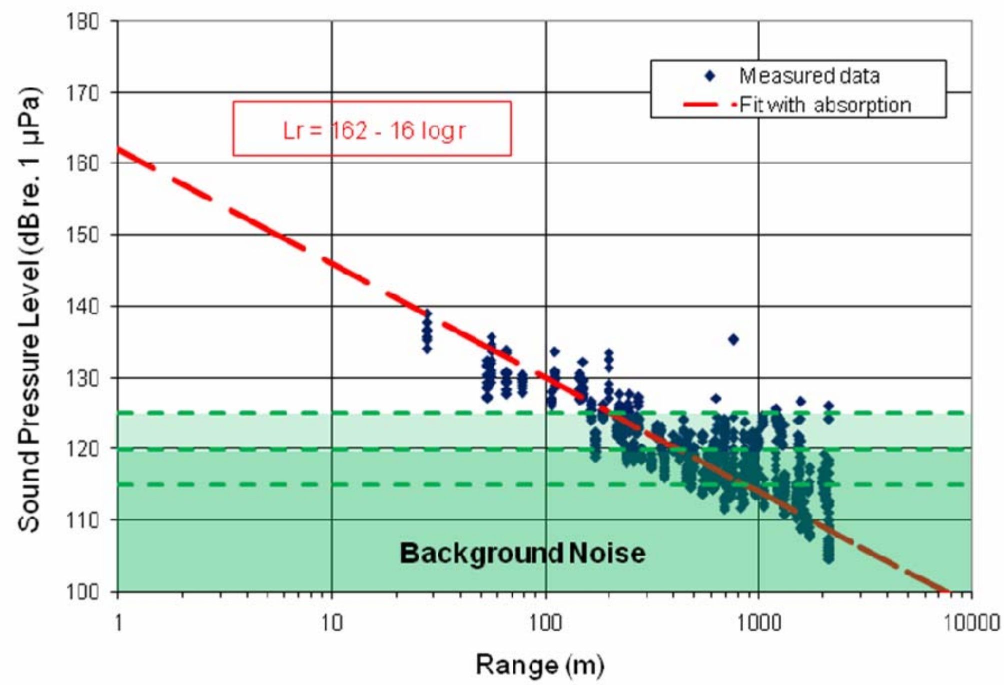

Figure 3-9. Variation of measured Sound Pressure Level with range during foundation drilling operations for the SeaGen tidal turbine device, Strangford Lough.

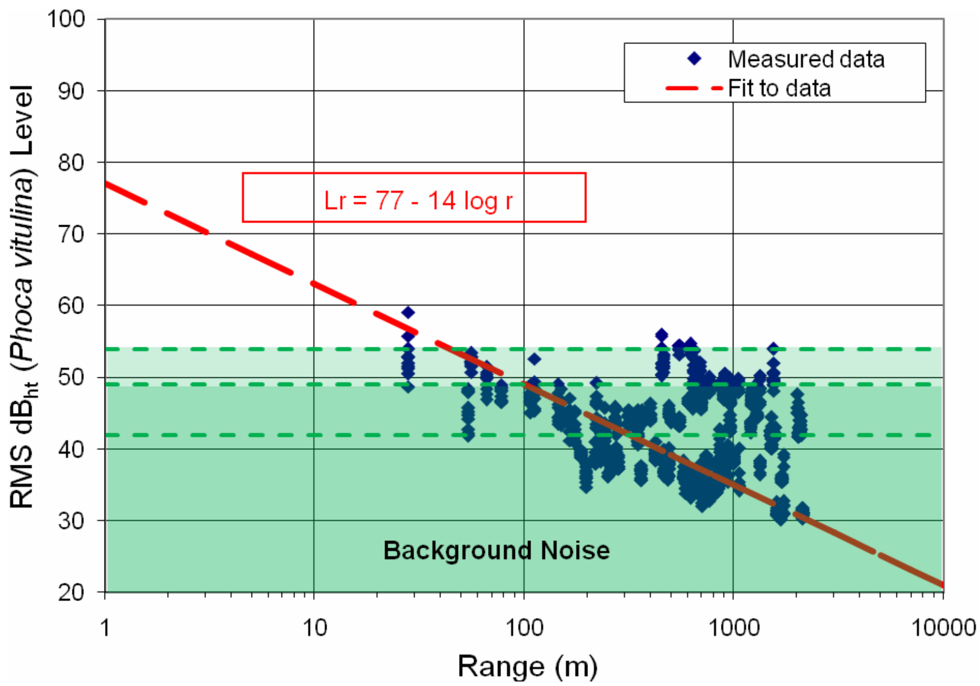

Figure 3-10. Measured underwater noise during drilling operations as part of the installation of the SeaGen tidal current turbine device, Strangford Lough, analysed in terms of the sound perception by the common seal (Phoca Vitulina).

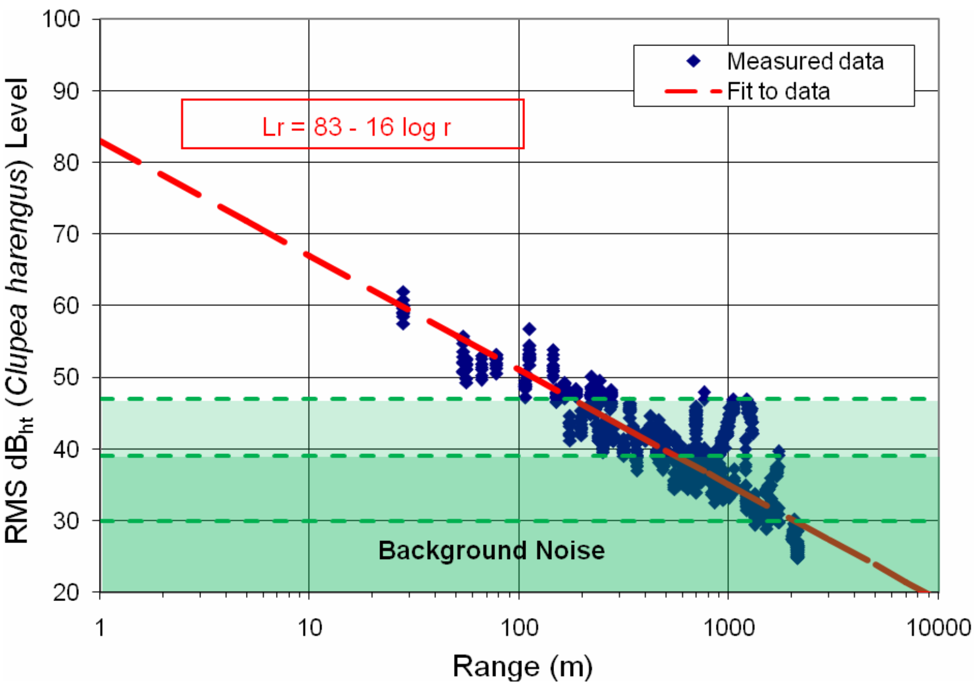

Figure 3-11. Measured underwater noise during drilling operations as part of the installation of the SeaGen tidal current turbine device, Strangford Lough, analysed in terms of the sound perception by the herring (Clupea harengus).

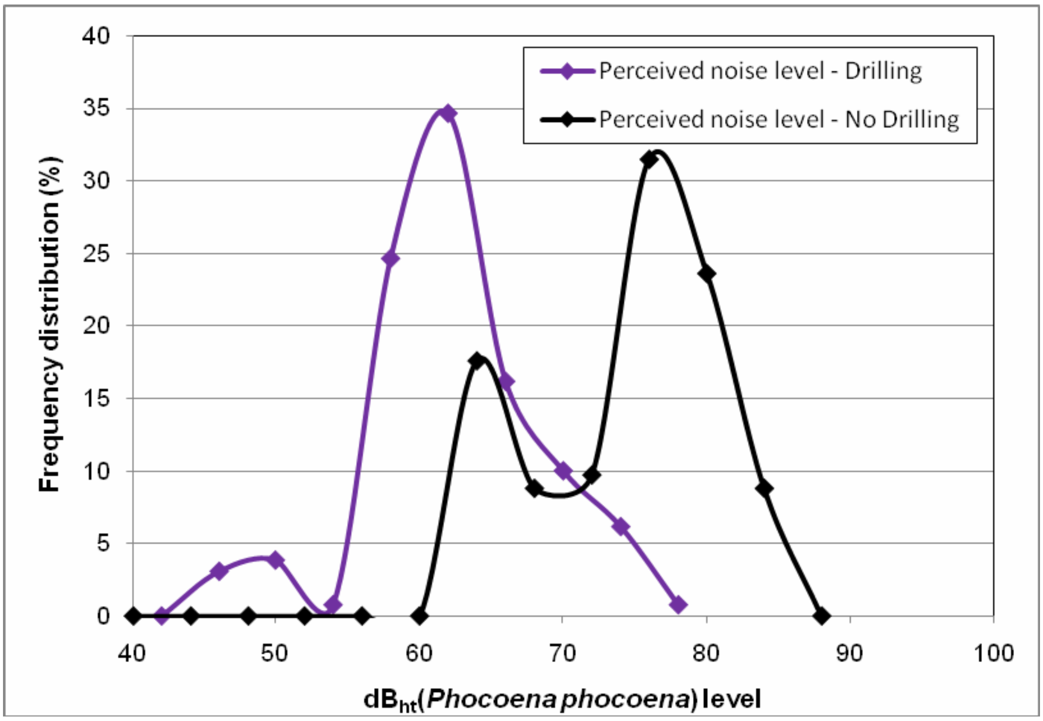

Figure 3-12 Summary of one second, RMS dB$_{ht}$ levels for the harbour porpoise measured at ranges of between 28 m and 200 m from the drilling operation, in comparison with perceived levels of background underwater noise, Strangford Lough. Data is presented as a frequency distribution of perceived levels

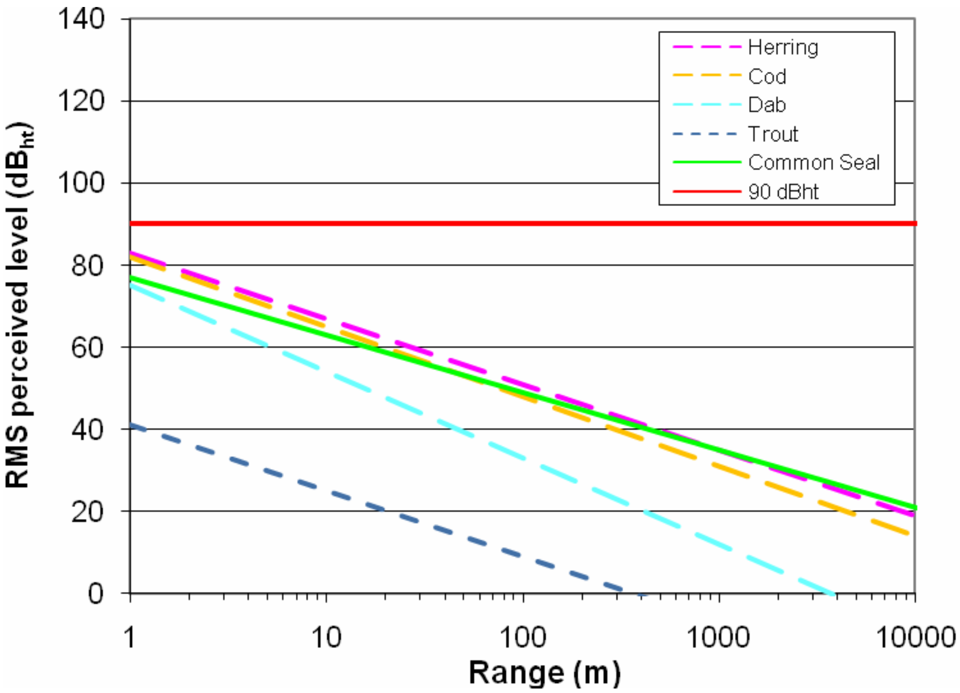

Figure 3-13 Summary of dB_{ht} levels with range from measurements during pin pile drilling operations as part of the installation of the SeaGen tidal current turbine device, Strangford Lough. The data presented is for selected species of fish and the common seal

4 Summary and Conclusions

1. A series of underwater noise measurements were undertaken during drilling operations for the pin piles used to secure the quadropod base of the SeaGen tidal turbine device. Measurements at ranges of 28 m to 2130 m from the drilling operation indicated that unweighted, one second Sound Pressure Levels varied from 105 to 139 dB re. 1 µPa. The fit to the measured data indicated a Source Level noise at a range of 1 m from the drilling operation of 162 dB re. 1 µPa. The levels of underwater noise from the drilling operation are comparable with small vessel noise and considerably lower than the levels of noise generated by other piling techniques such as impact piling or vibro-piling.
2. The measured levels of underwater noise, and the fit to the measured data indicate that the noise levels from the drilling operation are considerably lower than those that may cause fatality, physical injury or audiological injury to species of fish and marine mammal.
3. Behavioural avoidance of the drilling noise by species of fish and marine mammal has been assessed by comparing the measured noise levels with the published hearing threshold data for the species considered. The data indicates that the noise does not exceed the 90 dB_{ht} strong likelihood of disturbance level at any range from the drilling operation. The 75 dB_{ht} behavioural avoidance range for the species considered extends to a maximum of 3 m from the drilling, while the 50 dB_{ht} low likelihood of disturbance range extends to a maximum range of 115 m.
4. The data therefore indicates that species of fish and marine mammal are unlikely to be disturbed by the drilling noise unless they are in the close vicinity of the drilling operation.
5. Measurements of background underwater noise during periods when no drilling was being carried out have indicated high levels of high frequency noise are present in the Strangford Narrows region of Strangford Lough. It is thought that this is due to the high levels of tidal flow in the region generating noise by interaction of turbulent water with the sea bed and at the water surface.
6. Comparison of the measured background noise data with the hearing sensitivity of the harbour porpoise has indicated that this region is a noisy environment for marine animals that are sensitive to high frequency noise. The data for the drilling noise indicates that these species are unlikely to be able to hear noise from the drilling operation over the high levels of perceived background noise. This conclusion highlights the importance of assessing the spectral levels of underwater noise when estimating its impact on marine animals.

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A Underwater Sound Measurements

Units of measure

The fundamental unit of sound pressure is the Newton per square metre, or Pascal. However, in quantifying underwater acoustic phenomena it is convenient to express the sound pressure (either peak, or Root Mean Square (RMS)) as a Sound Pressure Level (SPL) through the use of a logarithmic scale.
There are three reasons for this:

- there is a very wide range of sound pressures measured underwater, from around 0.0000001 Pascal in quiet sea to say 10000000 Pascal for an explosive blast. The use of a logarithmic scale compresses the range so that it can be easily described (in this example, from 0 dB to 260 dB re. 1 μPa (referenced to a sound level of 1 μPa)).

- many of the mechanisms affecting sound underwater cause loss of sound at a constant rate when it is expressed on the dB scale.

- the effects of noise tend to increase in proportion to the SPL rather than the linear level. For instance, a given increase in effect will occur each time the sound is doubled, rather than each time it increases by a given unit of pressure.

The Sound Pressure Level, or SPL, is defined as

$$SPL = 20\log\left(\frac{P}{P_{ref}}\right) \qquad \text{eqn. A.1.}$$

where P is the sound pressure to be expressed on the scale and Pref is the reference pressure, which for underwater applications is 1 μPa.

Peak level

The peak level of the noise is the maximum variation in the acoustic pressure from the ambient level within the measurement period. Peak pressures are often quoted for underwater blast measurements where there is a clear positive peak following detonation.

Peak-to-peak level

The peak-to-peak level is calculated using the maximum variation of the pressure from positive to negative within the wave. Where the wave is symmetrically distributed in positive and negative pressure, the peak-to-peak level will be twice the peak level, and hence 6 dB higher.

Root-Mean-Square (RMS) level

For both continuous sound, or sound that varies in level, the RMS is used as an "average" value when calculating the level. The time period over which the averaging is conducted has to be quoted as this will influence the average level. For instance, in the case of a pile strike lasting say a tenth of a second, the mean taken over a tenth of a second will be ten times higher than the mean taken over one second.

Source Level

Where there is a well-defined source of noise, underwater sound pressure measurements may be expressed as dB re 1 μPa @ 1m, which represents the apparent level at a distance of one metre from the source. In fact, since the measurements are usually made at some distance from the source, and extrapolated back to the source, the true level at one metre may be very different from the Source Level. The Source Level may itself be quoted in any of the measures above, for instance, a piling source may be expressed as having a "peak-to-peak Source Level of 200 dB re 1 μPa @ 1 metre".

Sound Exposure Level

The degree by which a noise source affects marine animals may depend on the duration the sound is present above background levels. Sound Exposure Level (SEL) takes into account both the SPL of the sound source and the duration the sound is present in the acoustic environment. Sound Exposure (SE) is defined by the equation:

$$SE = \int_0^T p^2(t)dt \qquad \text{eqn. A.2}$$

Where p is the acoustic pressure in pascals, T is the duration of the sound in seconds and t is time.

Equation 2-4 gives units of pascal squared seconds (Pa^2-s).
The SE can be expressed as a deciBel level by using a reference pressure (P_{ref}) and a reference time (T_{ref}) on a logarithmic scale giving Sound Exposure Level (SEL):

$$SEL = 10\log_{10}\left(\frac{\int_0^T p^2(t)dt}{P_{ref}^2 T_{ref}}\right) \qquad \text{eqn. A.3}$$

P_{ref} and T_{ref} are typically 1 μPa and 1 second respectively for underwater noise.

Equation 2-5 can also be expressed by:

$$SEL = SPL + 10\log_{10}(T) \qquad \text{eqn. A.4}$$

Where T is the duration of the noise in seconds.
Using the reference pressures above Equation A.4 shows that for a sound of 1 second duration the Sound Exposure Level is equal to the Sound Pressure Level as $10\log_{10}(1) = 0$. For a sound of 10 seconds duration the SEL will be 10 dB higher than the SPL, for a sound of 100 seconds duration the SEL will be 20 dB higher than the SPL and so on.

Particle velocity

The use of particle velocity as an alternative or compliment to sound pressure has been advocated for sound measurements. There is evidence that many species of fish are sensitive to particle velocity rather than pressure (Hawkins, (1981)) Hastings and Popper (2005)).
Particle velocity defines the movement of the particles of a medium under the influence of a sound wave. In a free acoustic field, the particle motion is related to the acoustic pressure by the expression;

$$P = v.\ Z \qquad \text{eqn. A-5.}$$

Where *v* is the particle displacement under the influence of an acoustic pressure P, in a medium with an acoustic impedance Z. It is common to quote the level referenced to the particle velocity of a 1 Pa plane wave. For deep water, this has the advantage that the level of the sound is the same whether quoted in particle velocity or pressure and hence, measurements of acoustic pressure undertaken with a hydrophone can be converted to units of particle velocity.

Frequency content

To interpret an underwater sound signal for the manner in which it will be heard by an underwater animal, the sound signal in a time history format must be converted into its frequency components. This is because the response of marine species to underwater sound is frequency dependent (see audiograms for the salmon and trout in Figure 2-1). This transformation of the sound is achieved by performing a Power Spectral Density (PSD) analysis of the signal. 'The PSD's (frequency spectra) presented in this report may therefore be regarded as dividing up the total power of the sound into its frequency components, and are presented in deciBels referenced to 1 μPa.

The dB_{ht} (*Species*)

Measurement of sound using electronic recording equipment provides an overall linear level of that sound. The level that is obtained depends upon the recording bandwidth and sensitivity of the equipment used. This, however, does not provide an indication of the impact that the sound will have upon a particular fish or marine mammal species. This is of fundamental importance when considering the behavioural impact of underwater sound, as this is associated with the perceived loudness of the sound by the species. Therefore, the same underwater sound will affect marine species in a different manner depending upon the hearing sensitivity of that species.

The measurements of noise in this study have therefore also been presented in the form of a dBht level for the species. This scale incorporates the concept of "loudness" for a species. The metric incorporates hearing ability by referencing the sound to the species' hearing threshold, and hence evaluates the level of sound a species can perceive. In Figure A-1, the same noise spectrum is perceived at a different loudness level depending upon the particular fish or marine mammal receptor. The aspect of the noise that can be heard is represented by the 'hatched' region in each case. The receptors also hear different parts (components) of the noise spectrum. In the case shown, Fish 1 has the poorest hearing (highest threshold) and only hears the noise over a limited low frequency range. Fish 2 has very much better hearing and hears the main dominant components of the noise. Although having the lowest threshold to the sound, the marine mammal only hears the very high components of the noise and so it may be perceived as relatively quiet.

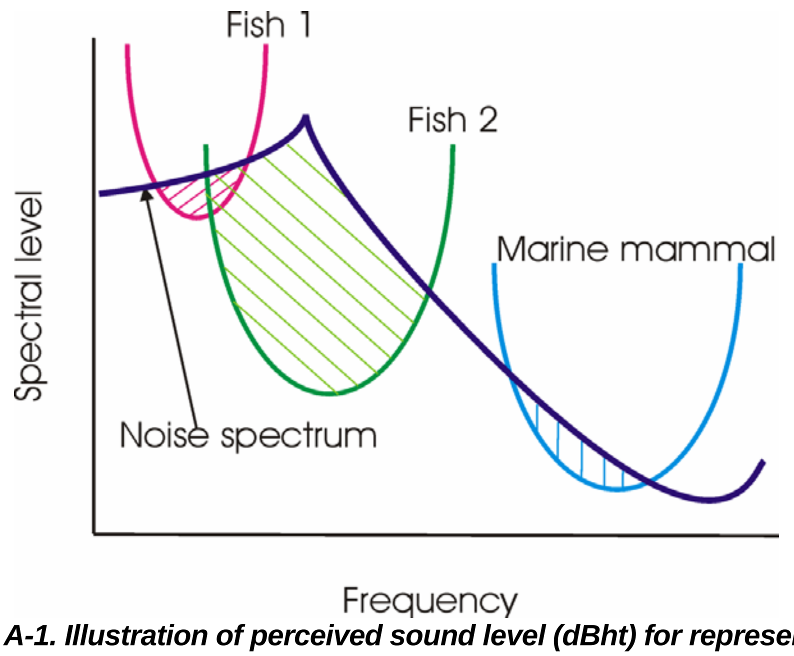


Figure A-1. Illustration of perceived sound level (dBht) for representative fish and marine mammal species.

Since any given sound will be perceived differently by different species (since they have differing hearing abilities) the species name must be appended when specifying a level. For instance, the same sound might have a level of 70 dBht (*Gaddus morhua*) for a cod and 40 dBht (*Salmo salar*) for a salmon.

The perceived noise levels of sources measured in dBht (species) are usually much lower than the un-weighted (linear) levels, both because the sound will contain frequency components that the species cannot detect, and also because most aquatic and marine species have high thresholds of perception to (are relatively insensitive to) sound.

Background levels.

Of critical importance in assessing the impact of noise from an activity is a measure of the ambient noise environment. The pre-existing noise levels in fast flowing rivers, busy estuaries and coastal waters will be high compared to the levels that are associated with airborne perception by terrestrial animals. As an example, ambient underwater noise in coastal waters measured as a broadband level from 1 Hz to 100 kHz, typically varies from 120 to 145 dB re. 1 μPa.

Attenuation of sound

To normalise underwater sound measurements to a common reference point, levels are normally quoted as Source Levels. As the sound propagates out from the source the level will reduce in level both as a result of geometric spreading and absorption in the propagation medium. These effects when combined provide a model for the Transmission Loss (TL) of the noise with range. This means that the received level at range is substantially lower than the Source Level in the immediate vicinity of the activity.

The sound level at range from an activity can be described by the expression;

$$L(r) = SL - TL \qquad \text{eqn. A.6}$$

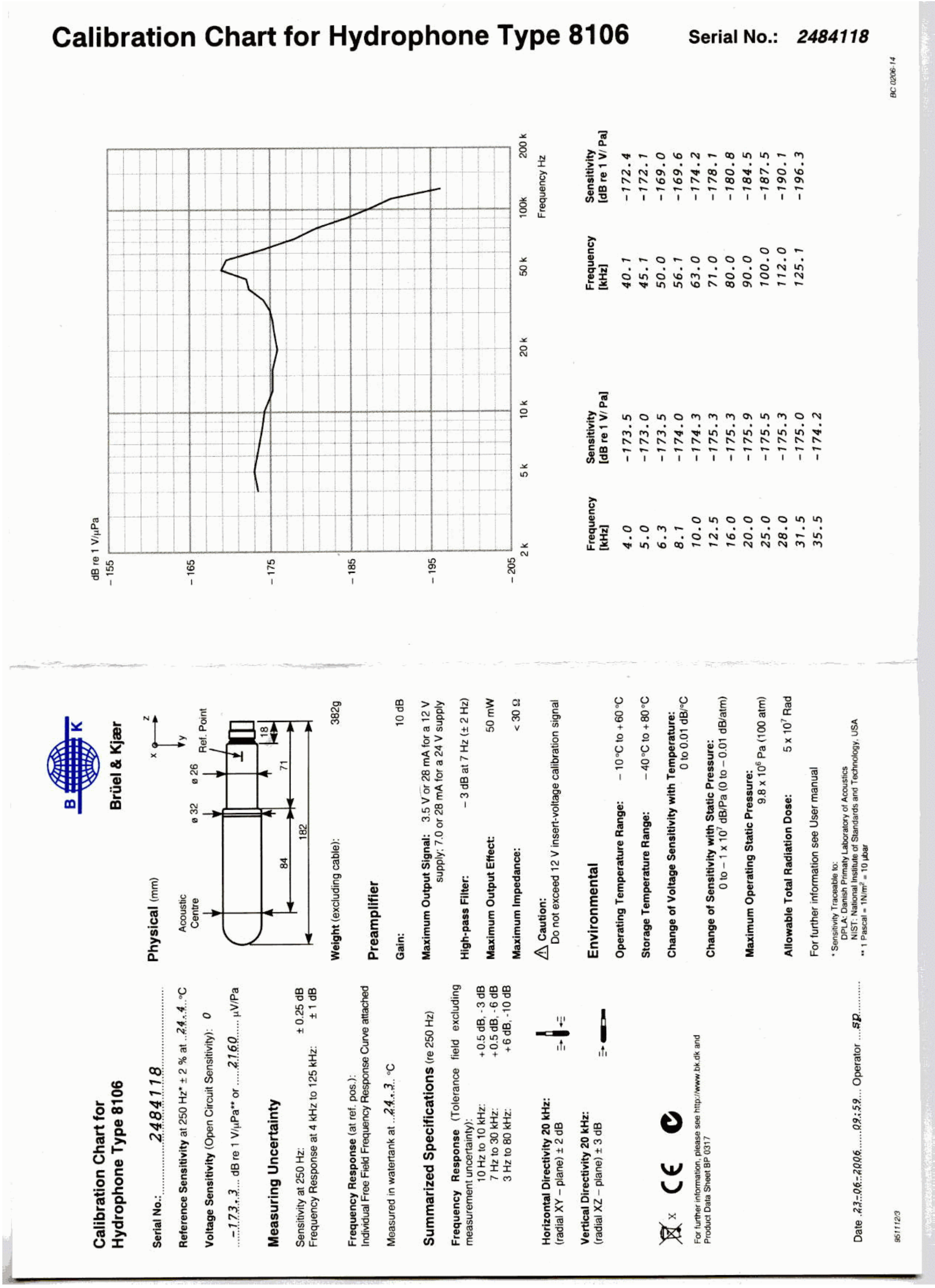
where L(r) is the Sound Pressure Level at distance r from a source (m), SL is the (notional) source level at 1 m from the source, and TL is the transmission loss.
The Transmission Loss is frequently described by the equation

$$TL = N \log(r) + \alpha r \qquad \text{eqn. A.7}$$

where r is the distance from the source (m), N is a factor for attenuation due to geometric spreading, and α is a factor for the absorption of sound in water and boundaries (dB.m-1). Using this form of sound transmission loss, the sound level with range L(r) can be described by the expression

$$L(r) = SL - N \log(r) - \alpha r \qquad \text{eqn. A.8}$$

B Calibration Charts



Calibration Chart for Hydrophone Type 8106 Serial No.: *2484118*

Calibration Chart for Hydrophone Type 8106

Brüel & Kjær

Serial No.: 2484118

Reference Sensitivity at 250 Hz* ± 2 % at 24.4 °C

Voltage Sensitivity (Open Circuit Sensitivity): 0

–173.3 dB re 1 V/μPa** or 2160 μV/Pa

Measuring Uncertainty

Sensitivity at 250 Hz: ± 0.25 dB
Frequency Response at 4 kHz to 125 kHz: ± 1 dB

Frequency Response (at ref. pos.):
Individual Free Field Frequency Response Curve attached

Measured in watertank at 24.3 °C

Summarized Specifications (re 250 Hz)

Frequency Response (Tolerance field excluding measurement uncertainty):
10 Hz to 10 kHz: +0.5 dB, -3 dB
7 Hz to 30 kHz: +0.5 dB, -6 dB
3 Hz to 80 kHz: +6 dB, -10 dB

Horizontal Directivity 20 kHz:
(radial XY – plane) ± 2 dB

Vertical Directivity 20 kHz:
(radial XZ – plane) ± 3 dB

For further information, please see http://www.bk.dk and Product Data Sheet BP 0317

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Physical (mm)

Weight (excluding cable): 382g

Preamplifier

Gain: 10 dB

Maximum Output Signal: 3.5 V or 28 mA for a 12 V supply; 7.0 or 28 mA for a 24 V supply

High-pass Filter: – 3 dB at 7 Hz (± 2 Hz)

Maximum Output Effect: 50 mW

Maximum Impedance: < 30 Ω

Caution:
Do not exceed 12 V insert-voltage calibration signal

Environmental

Operating Temperature Range: – 10 °C to + 60 °C

Storage Temperature Range: – 40 °C to + 80 °C

Change of Voltage Sensitivity with Temperature: 0 to 0.01 dB/°C

Change of Sensitivity with Static Pressure: 0 to – 1 x 10^7 dB/Pa (0 to – 0.01 dB/atm)

Maximum Operating Static Pressure: 9.8 x 10^6 Pa (100 atm)

Allowable Total Radiation Dose: 5 x 10^7 Rad

For further information see User manual

* Sensitivity Traceable to:
DPLA: Danish Primaty Laboratory of Acoustics
NIST: National Institute of Standards and Technology, USA
** 1 Pascal = 1N/m² = 10 μbar

Frequency [kHz]	Sensitivity [dB re 1 V/ Pa]	Frequency [kHz]	Sensitivity [dB re 1 V/ Pa]
4.0	-173.5	40.1	-172.4
5.0	-173.0	45.1	-172.1
6.3	-173.5	50.0	-169.0
8.1	-174.0	56.1	-169.6
10.0	-174.3	63.0	-174.2
12.5	-175.3	71.0	-178.1
16.0	-175.3	80.0	-180.8
20.0	-175.9	90.0	-184.5
25.0	-175.5	100.0	-187.5
28.0	-175.3	112.0	-190.1
31.5	-175.0	125.1	-196.3
35.5	-174.2		

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Issue	Date	Details of changes
724R0112	24/06/2008	Internal review
724R0113	27/06/2008	Internal review – Additional analysis
724R0114	01/07/2008	Internal amendments
724R0115	02/07/2008	First draft and issue to customer for comments
724R0116	13/08/2008	Additional information on drilling techniques added
724R0117	26/08/2008	Amendments following comments
724R0118	28/08/2008	Internal amendments
724R0119	03/08/2008	Internal review
724R0120	04/08/2008	Final report issued to customer

1. Originator's current report number	724R0120
2. Originator's Name & Location	J.R Nedwell, Subacoustech Ltd
3. Contract number & period covered	724, April - August 2008
4. Sponsor's name & location	
5. Report Classification & Caveats in use	COMMERCIAL IN CONFIDENCE
6a. Date written	June 2008
6b. Pagination	Cover + iii + 33
6c. References	47
7a. Report Title	
7b. Translation / Conference details (if translation give foreign title / if part of conference then give conference particulars)	
7c. Title classification	UNCLASSIFIED
8. Authors	**J.R.Nedwell and A.G. Brooker**
9. Descriptors / Key words	.
10a. Abstract	
10b. Abstract classification	UNCLASSIFIED; UNLIMITED DISTRIBUTION.